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TITLE: SWITCHED-RELUCTANCE  
MOTOR CONTROL

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## SWITCHED-RELUCTANCE MOTOR CONTROL

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### BACKGROUND OF THE INVENTION

#### 1. FIELD OF THE INVENTION

The present invention generally relates to a control of a switched-reluctance 10 motor. The present invention specifically relates to a brake-by-wire system having a switched-reluctance motor that is controlled during a pre-alignment braking phase, a preliminary braking phase, and a primary braking phase.

#### 2. DESCRIPTION OF THE RELATED ART

15       Switched-reluctance motors are emerging as a prime candidate for various applications (e.g., automotive brake applications), because switched-reluctance motors provide an advantage of a large peak-torque capability on an intermittent basis and an advantage of a large speed range. Additionally, switched-reluctance motors have inherent fault tolerant features.

20       A switched-reluctance motor operates on the principle of variable reluctance, and typically includes a stator pole, a plurality of windings, and a rotor, such as a stator 20, windings 31-38, and a rotor 40 forming a 4-phase, 8 stator pole/6 rotor pole switched-reluctance motor as shown in FIGS. 1A-1D. Stator 20 includes stator poles 21-28, and rotor 40 includes rotor poles 41-46. Windings 31-38 are wrapped 25 around stator poles 21-28, respectively.

25       Winding 31 and winding 35 are electrically coupled (not shown) to define a phase A of the motor whereby a phase current flowing through winding 31 and winding 35 generates diametric magnetic fields around stator pole 21 and stator pole 26. Winding 32 and winding 36 are electrically coupled (not shown) to define a 30 phase B of the motor whereby a phase current flowing through winding 32 and winding 36 generates diametric magnetic fields around stator pole 22 and stator pole 26. Winding 33 and winding 37 are electrically coupled (not shown) to define a

phase C of the motor whereby a phase current flowing through winding 33 and winding 37 generates diametric magnetic fields around stator pole 23 and stator pole 27. Winding 34 and winding 38 are electrically coupled (not shown) to define a 5 phase D of the motor whereby a phase current flowing through winding 34 and winding 38 generates diametric magnetic fields around stator pole 24 and stator pole 28.

Rotor 40 is typically made of iron, and as a result, rotor 40 can be rotated about an axis 40a in response to a generation of one or more pairs of diametric 10 magnetic fields. Phase currents are therefore strategically provided to windings 31-38 to thereby rotate rotor 40 about axis 40a in a clockwise direction or in a counterclockwise direction. Stator 20, windings 31-38, and rotor 40 are housed within a system (e.g., a electrically-actuated brake system) with the rotor 40 being coupled to an actuating member (e.g., a planetary gear assembly) of the system 15 whereby the actuating member concurrently rotates about axis 40a in response to any rotation of rotor 40 about axis 40a.

Various complicated phase current control schemes have been devised for determining a rotational position of rotor 40, for rotating rotor 40 over a large speed range, for avoiding local overheating of the switched-reluctance motor, and for 20 minimizing the ampere levels of the phase currents. The present invention addresses a need for a simplified phase current control scheme for comprehensively controlling a positioning and a rotation of rotor 40 about axis 40a.

#### SUMMARY OF THE INVENTION

25 One form of the present invention is method of controlling an operation of a switched-reluctance motor including a stator having a stator pole and a rotor having a rotor pole. First, the rotor pole and the stator pole are aligned in response to a reception of an actuation command. Second, the rotor is cranked in a direction dictated by the actuation command for a predetermined time period. Third, the 30 rotor is rotated to a holding position upon an expiration of the predetermined time period. Finally, any operational losses of the switched-reluctance motor are minimized when the rotor is in the holding position.

A second form of the present invention is a device for controlling an operation of a switched-reluctance motor including a stator having a stator pole and a rotor having a rotor pole. The system comprises the following means. A means 5 for aligning the rotor pole and the stator pole in response to a reception of an actuation command. A means for cranking the rotor in a direction dictated by the actuation command for a predetermined time period. A means for rotating the rotor to a holding position upon an expiration of the predetermined time period. And, a means for minimizing any operational losses of the switched-reluctance motor when 10 the rotor is in the holding position.

A third form of the present invention is a switched-reluctance motor including a stator having a stator pole, and a rotor having a rotor pole. The switched-reluctance motor further comprises the following means. A means for aligning the rotor pole and the stator pole in response to a reception of an actuation 15 command. A means for cranking the rotor in a direction dictated by the actuation command for a predetermined time period. A means for rotating the rotor to a holding position upon an expiration of the predetermined time period. And, a means for minimizing any operational losses of the switched-reluctance motor when the rotor is in the holding position.

20 The foregoing forms, and other forms, features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the 25 appended claims and equivalents thereof.

## BRIEF DESCRIPTION OF THE DRAWINGS

**FIG. 1A** is a diagrammatic cross-sectional view of a stator pole, windings, and a rotor of a prior art 4-phase, 8 stator pole/6 rotor pole switched-reluctance motor with phase A aligned;

**FIG. 1B** is a diagrammatic cross-sectional view of a stator pole, windings, and a rotor of a prior art 4-phase, 8-stator pole/6 rotor pole switched-reluctance motor with phase B aligned;

**FIG. 1C** is a diagrammatic cross-sectional view of a stator pole, windings, and a rotor of a prior art 4-phase, 8-stator pole/6 rotor pole switched-reluctance motor with phase C aligned;

**FIG. 1D** is a diagrammatic cross-sectional view of a stator pole, windings, and a rotor of a prior art 4-phase, 8-stator pole/6 rotor pole switched-reluctance motor with phase D aligned;

**FIG. 2** is block diagram of one embodiment of a control device of the present invention;

**FIG. 3** is flow chart of one embodiment of a master control routine implemented by the **FIG. 2** control device;

**FIG. 4A** is flow chart of a first embodiment of a pre-alignment control routine implemented by the **FIG. 2** control device;

**FIG. 4B** illustrates exemplary graphs of phase currents employed during an implementation of the **FIG. 4A** pre-alignment control routine;

**FIG. 5A** is flow chart of a second embodiment of a pre-alignment control routine implemented by the **FIG. 2** control device;

**FIG. 5B** is a first exemplary graph of a torque characteristic of the rotor of the **FIG. 1** switched-reluctance motor versus a rotational position of the rotor;

**FIG. 5C** illustrates exemplary graphs of phase currents employed during an implementation of the **FIG. 5A** pre-alignment control;

**FIG. 6A** is flow chart of one embodiment of a preliminary control routine implemented by the **FIG. 2** control device;

**FIG. 6B** illustrates exemplary graphs of phase currents employed during an implementation of the **FIG. 6A** preliminary control routine;

5      **FIG. 7A** is flow chart of one embodiment of a primary control routine implemented by the **FIG. 2** control device;

**FIG. 7B** illustrates exemplary graphs of phase currents employed during an implementation of the **FIG. 7A** primary control routine;

**FIG. 8A** is flow chart of a second embodiment of primary control routine implemented by the **FIG. 2** control device;

10     **FIG. 8B** is a second exemplary graph of a torque characteristic of the rotor of the **FIG. 1** switched-reluctance motor versus a rotational position of the rotor; and

**FIG. 8C** illustrates an exemplary graph of a phase current employed during an implementation of the **FIG. 8A** primary control routine.

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#### DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

A control device **50** of the present invention is shown in **FIG. 2**. Control device **50** comprises a controller **51** and a switched-reluctance motor interface **54**.  
20     Control device **50** optionally comprises a rotor position sensor **55**.

Controller **51** is preferably an electronic circuit comprised of one or more components that are assembled as a common unit within a system (e.g., a electrically-actuated brake system). Alternatively, for the multiple component embodiments, one or more of these components may be distributed throughout the  
25     system housing controller **51**. Controller **51** may be comprised of digital circuitry, analog circuitry, or both. Also, controller **51** may be programmable, a dedicated state machine, or a hybrid combination of programmable and dedicated hardware. To implement the principles of the present invention, controller **51** can further include any control clocks, interfaces, signal conditioners, filters, Analog-to-Digital  
30     (A/D) converters, Digital-to-Analog (D/A) converters, communication ports, or other types of operators as would occur to those having ordinary skill in the art.

In one embodiment, controller 51 includes a microprocessor 52 operatively coupled to one or more solid-state memory devices 53. Microprocessor 52 is preferably a microprocessor from one the Intel, AMD, or Motorola families of microprocessors. Memory 53 is one or more computer readable mediums (e.g., a read-only memory, an erasable read-only memory, a random access memory, a compact disk, a floppy disk, a hard disk drive, and other known forms) that are electrically, magnetically, optically or chemically altered to contain computer readable code corresponding to a master control routine 60 (FIG. 3) for intelligently providing a commutation control signal CCs to interface 54, and is arranged for reading and writing of data in accordance with the principles of the present invention. In alternative embodiments of controller 51, the computer program product corresponding to master control routine 60 (FIG. 3) can otherwise be partially or fully implemented by digital circuitry, analog circuitry, or both (e.g., an application specific integrated circuit (ASIC))

Switched-reluctance motor interface 54 receives commutation control signal CCs from controller 51. In response thereto, switched-reluctance motor interface 54 is designed to conventionally commutate, separately or concurrently, one or more phases A-D of windings 31-38 to thereby control a rotation of rotor 40 (FIG. 1) about axis 40a (FIG. 1). Specifically, interface 54 provides a phase current signal  $I_{PS1}$  as commanded by commutation control signal CCs through winding 31 and winding 35, a phase current signal  $I_{PS2}$  as commanded by commutation control signal CCs through winding 32 and winding 36, a phase current signal  $I_{PS3}$  as commanded by commutation control signal CCs through winding 33 and winding 37, and a phase current signal  $I_{PS4}$  as commanded by commutation control signal CCs through winding 34 and winding 38. Those having ordinary skill in the art will appreciate the various embodiments of interface 54 as known in the art, such as, for example, an arrangement of switches in the form of MOSFET transistors.

When rotor position sensor 55 is included within control device 50, rotor position sensor 55 conventionally provides a position detection signal PDs to controller 51. Position detection signal PDs is indicative of a sensed rotational position of rotor 40 (FIG. 1) whereby controller 51 can conventionally estimate the position of rotor 40. Those having ordinary skill in the art will appreciate the various embodiments of rotor position sensor 55 as known in the art, such as, for example, an arrangement of Hall Effect sensors, encoders, and the like.

Alternatively, when rotor position sensor 55 is excluded from control device 50, 10 interface 54 implements algorithms known in the art to estimate the position of rotor 40 as a function of phase currents  $I_{PS1}, I_{PS4}$ .

Referring additionally to FIG. 3, routine 60 comprises a pre-alignment stage S62, a preliminary stage S64 and a primary stage S66. Routine 60 is described herein in conjunction with the 4-phase 8 stator pole/6 rotor pole switched-reluctance 15 motor shown in FIGS. 1A-1D. Those having ordinary skill in the art however will appreciate the applicability of routine 60 to other types of switched-reluctance motors.

During stage S62, controller 51 executes a pre-alignment routine 70 as shown in FIG. 4A in one embodiment of routine 60 and a pre-alignment routine 80 20 as shown in FIG. 5A in another embodiment of routine 60. Routines 70 and 80 are for aligning one of the rotor poles 41-46 (FIG. 1) with one of the stator poles 21-28 (FIG. 1) in response to an actuation command AC from a device (e.g., a brake-by-wire controller) (not shown) of a system housing control device 50.

Referring to FIGS. 1A-1D, 4A, and 4B, during a stage S72 of routine 70, 25 controller 51 identifies a target phase for defining an initial position of rotor 40. In one embodiment, the identification of the target phase is retrieved from memory 53. For example, microprocessor 52 can retrieve from memory 53 the identification of phase A (FIG. 1A) as the target phase.

During a stage **S74** of routine **70**, controller **51** controls an excitement of a phase adjacent to the target phase to thereby position rotor **40** whereby the target phase is misaligned. The excitation is accomplished by controller **51** directing interface **54** via commutation control signal **CCs** to provide a corresponding phase current to the corresponding windings. For example, when phase A is the target phase, phase A may be aligned (i.e., a pair of rotor poles being aligned with stator pole **21** and stator pole **25**) as shown in **FIG. 1A**; phase A may be unaligned (i.e., a pair of rotor poles being equidistant from stator pole **21** and another pair of rotor poles being equidistant from stator pole **25**) as shown in **FIG. 1C**; or phase A may be misaligned (i.e., neither aligned or unaligned) as shown in **FIGS. 1B** and **1D**. Interface **54** directs a flow of a phase current  $I_{PS2}$  at an ampere level  $X_1$  through winding **32** and winding **36** for a time period  $t_1$  as shown in **FIG. 4B** to thereby rotate rotor **40** to a position whereby phase B is aligned (i.e., a pair of rotor poles being aligned with stator pole **22** and stator pole **26**) as shown in **FIG. 1B**; or phase B is unaligned position (i.e., a pair of rotor poles being equidistant from stator pole **22** and another pair of rotor poles being equidistant from stator pole **26**) as shown in **FIG. 1D**. As a result, phase A is misaligned as shown in **FIG. 1B** or **FIG. 1D**.

During a stage **S76** of routine **70**, controller **51** controls an excitement of the target phase to thereby position rotor **40** whereby the target phase aligned. The excitation is accomplished by controller **51** directing interface **54** via commutation control signal **CCs** to provide a corresponding phase current to the corresponding windings. For example, when phase A is the target phase, interface **54** directs a flow of a phase current  $I_{PS1}$  at ampere level  $X_1$  through winding **31** and winding **35** for a time period  $t_2$  as shown in **FIG. 4B** to thereby rotate rotor **40** to a position whereby phase A is aligned as shown in **FIG. 1A**.

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Controller **51** returns to routine **60** upon completion of stage **S76**. Those having ordinary skill in the art will appreciate that a benefit of routine **70** is the capability of controller **51** to subsequently control a cranking of rotor **40** in a desired direction. Referring to FIGS. **1A-1D**, and **5A-5C**, during a stage **S82** of routine **80**, controller **51** identifies a target position for defining an initial position of rotor **40**. In one embodiment of stage **S82**, the target position is selected as a function of maximizing the torque level experienced by an actuating member (e.g., a planetary gear system) being coupled to rotor **40** when rotor **40** is in the initial position, and the identification of the target position is retrieved from memory **52** by microprocessor **51**. For example, as shown in FIG. **5B**, a simulated rotation of rotor **40** can indicate a position of -23° from an alignment of phase A that provides the maximum torque level to the actuating member, and a rotation of rotor **40** from the -23° position of phase A aligned in a counterclockwise direction facilitates a minimum response time by rotor **40**. Accordingly, the -23° position of phase A aligned is stored in memory **53** as the target position.

During a stage **S84** of routine **80**, controller **51** controls an alignment of a phase adjacent the target position. In one embodiment of stage **S84**, controller **51** implements routine **70** during stage **S84** as previously described herein. For example, phase D is adjacent the -23° position of phase A aligned and interface **54** therefore directs a flow of phase current  $I_{Ps3}$  through winding **33** and winding **37** during stage **S74** to thereby rotate rotor **40** to a position whereby phase D is misaligned as shown in FIG. **1A** or in FIG. **1C**. Interface **54** thereafter directs a flow of phase current  $I_{Ps4}$  through winding **34** and winding **38** during stage **S76** to thereby rotate rotor **40** to a position whereby phase D is aligned as shown in FIG. **1D**.

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During a stage **S86** of routine **80**, controller **51** controls an excitement of two or more phases remote from the target position. The excitation is accomplished by controller **51** directing interface **54** via commutation control signal **CCs** to provide corresponding phase currents to the corresponding windings with a differential ampere level between the phase currents of the remote phases. For example, phase A and phase B are the phases that are remote the -23 position of phase A aligned and interface **54** therefore directs a flow of phase current  $I_{PS1}$  through winding **31** and winding **35** at an ampere level  $X_2$  for a time period  $t_3$  and a flow of phase current  $I_{PS2}$  winding **32** and winding **36** at ampere level  $X_1$  for time period  $t_2$  to thereby rotate rotor **40** to the -23 position of phase A aligned as shown in **FIG. 5B.**

In an alternative embodiment of stage **S86**, controller **51** utilizes the position detection signal  $P_{DS}$  from sensor **55** during stage **S84** and stage **S86** to direct interface **54** via commutation control signal **CCs** to provide the appropriate phase current(s) whereby rotor **40** is rotated to the -23 position of phase A aligned as shown in **FIG. 5B.**

Controller **51** returns to routine **60** upon completion of stage **S86**. Those having ordinary skill in the art will appreciate that benefit of routine **80** is the capability of controller **51** to subsequently control a cranking of rotor **40** in a desired direction within a minimized response time.

Referring to **FIGS. 2 and 3**, controller **51** proceeds to stage **S64** of routine **60** upon a completion of stage **S62**. During stage **S64**, controller **51** executes a preliminary control routine **90** as shown in **FIG. 6A.**

Referring to **FIGS. 1A-1D, 6A and 6B**, during a stage **S92** of routine **90**, controller **51** cranks rotor **40** in a desired direction for a predetermined time period. In one embodiment of stage **S92**, controller **51** controls a sequential excitement of phases for one or more cycles to thereby crank rotor **40** in a desired direction (e.g., in a direction of a holding position corresponding to a predetermined range of rotation from the initial position) as dictated by the actuation command **AC**. The sequential excitation is accomplished by controller **51** directing interface **54** via commutation control signal **CCs** to sequentially provide corresponding phase currents to the corresponding windings for one or more cycles. For example, as

shown in FIG. 6B, when phase A aligned represents the initial position of rotor 40 and the holding position is in a counterclockwise direction therefrom, interface 54 directs a flow of phase current  $I_{PS2}$  through winding 32 and winding 36 for a time period  $t_4$  to thereby excite phase D whereby rotor 40 rotates in a counterclockwise direction. Interface 54 then directs a flow of phase current  $I_{PS3}$  through winding 33 and winding 37 for a time period  $t_5$  to thereby excite phase C whereby rotor 40 continues to rotate in a counterclockwise direction. Interface 54 then directs a flow of phase current  $I_{PS4}$  through winding 34 and winding 38 for a time period  $t_6$  to thereby excite phase B whereby rotor 40 continues to rotate in a counterclockwise direction. Interface 54 then directs a flow of phase current  $I_{PS1}$  through winding 31 and winding 35 for a time period  $t_7$  to thereby excite phase A whereby rotor 40 continues to rotate in a counterclockwise direction. The sequential excitation of one or more phases B-C-D-A can be repeated as needed for rotor 40 to crank rotor 40 in the desired direction (e.g., a direction of a holding position).

In one embodiment of stage S92, each time period  $t_{4-7}$  is fixed at a particular level (e.g., 2 milliseconds). In a second embodiment of stage S92, each time period  $t_{4-7}$  is fixed at one or more various levels (e.g.,  $t_4$  being 2 milliseconds,  $t_5$  being 1.8 milliseconds,  $t_6$  being 1.6 milliseconds, and  $t_7$  being 1.4 milliseconds). In a third embodiment of stage S92, controller 51 dynamically determines the levels of time periods  $t_{4-7}$  as a function of operating parameters of the motor as would occur to those having ordinary skill in the art, such as, for example, any load torque applied by the motor, a power supply for the motor, a temperature of the motor, and a responsiveness level of the motor to the phase currents  $I_{PS1-PS4}$ .

Upon expiration of the predetermined time period during stage S92, controller 51 proceeds to stage S94 of routine 90 to execute high speed routines as well known in the art whereby rotor 40 is rotated in the desired direction. Controller 51 terminates routine 90 upon completion of stage S94. In one embodiment of stage S94, rotor 40 is rotated until rotor 40 is positioned in a holding position.

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Referring to FIGS. 2 and 3, controller 51 proceeds to stage S66 of routine 60 to execute a primary control routine 100 as shown in FIG. 7A and a primary control routine 110 as shown in FIG. 8A. Routines 100 and 110 are for minimizing 5 any heating losses and any current losses, respectively, of the switched-reluctance motor when rotor 40 is positioned in the holding position.

Referring to FIGS. 1A-1D, 2, 7A and 7B, during a stage S102 of routine 100, controller 51 determines if rotor 40 is in the holding position. In one embodiment of stage S102, controller 51 determines rotor 40 is in the holding 10 position when a load force signal LFs indicates an actual load force on the actuating member approximates a desired load force on the actuating member that corresponds to the holding position as indicated by the actuation command AC. Load force signal LFs is provided to controller 51 by sensors known in the art.

Controller 51 proceeds to a stage S104 of routine 100 when controller 51 15 determines if rotor 40 is in the holding position during stage S102. During stage S104, controller 51 determines if rotor 40 has been in the holding position for a predetermined time period. In one embodiment of stage S104, interface 54 includes an arrangement of switches and either controller 51 or interface 54 includes a counter. The counter is utilized to count the time a particular switch corresponding 20 to the holding position is turned on. When controller 51 determines rotor 40 has been in the holding position for a predetermined time period, controller 51 proceeds to a stage S106 of routine 100 to control a dithering of rotor 40.

In one embodiment of stage S106, controller 51 directs interface 54 to sequentially excite phases adjacent the holding position for one or more time cycles. The sequential excitation is accomplished by controller 51 directing interface 54 via 25 commutation control signal CCs to sequentially provide corresponding phase currents to the corresponding windings for one or more cycles. For example, when the holding position corresponds to phase A aligned as shown in FIG. 1A and rotor 40 was rotated in a counterclockwise direction to the holding position, interface 54 directs a flow of phase current  $I_{Ps4}$  through winding 34 and winding 38 for a predetermined time period to thereby excite phase D whereby rotor 40 is rotated in 30 a clockwise direction. Interface 54 then directs a flow of phase current  $I_{Ps1}$  through

5 winding 31 and winding 32 for a predetermined time period to thereby again excite phase A whereby rotor 40 is rotated back to the holding position in a counterclockwise direction. The cycle of sequentially exciting phases D-A can be repeated as needed. In a second embodiment of stage S105, one or more cycles of sequentially exciting D-C-D-A is repeated as needed. In a third embodiment of stage S106, one or more cycles of sequentially exciting D-C-B-C-D-A is repeated as needed.

In a fourth embodiment of stage S106, controller 51 controls a decrease in 10 excitation of a phase corresponding to the holding position while maintaining a motor torque level corresponding to the holding position. This is accomplished by controller 51 directing interface 54 via commutation control signal CCs to decrease the ampere level of the phase current corresponding to the excited phase and to initiate the flow of a phase current through an adjacent phase at an ampere level that 15 will maintain the motor torque level. The motor torque level is a function of the design of the switched-reluctance motor, and controller 51 can therefore determine the motor torque level from a lookup table stored within memory 53.

For example, as shown in FIG. 7B, when the holding position corresponds to phase A aligned as shown in FIG. 1A and rotor 40 was rotated in a 20 counterclockwise direction to the holding position, interface 54 directs a flow of phase current  $I_{PS1}$  through winding 31 and winding 35 at an ampere level  $X_1$  for a time period  $t_8$  to excite phase A. Subsequently, interface 54 directs a flow of phase current  $I_{PS1}$  through winding 31 and winding 35 at an ampere level  $X_2$  that is lower than ampere level  $X_1$  during a time period  $t_9$ . Concurrently during time period  $t_9$ , 25 interface 54 directs a flow of phase current  $I_{PS2}$  through winding 32 and winding 34 at ampere level  $X_2$  to thereby simultaneously excite phase A and phase B.

A fifth embodiment of stage S106 involves a modification of the fourth embodiment of stage S106 whereby the motor torque level as retrieved from memory 53 is undulated about a fixed level after a fixed period of time. The 30 ampere levels of phase currents being supplied to the two phases are adjusted accordingly as appreciated by those having ordinary skill in the art.

Controller **51** returns to routine **60** upon completion of stage **S106**. Those having ordinary skill in the art will appreciate that benefit of routine **100** is the capability of controller **51** to prevent local overheating of stator **20**, windings **31-38**, and rotor **40**. As a result, stress within windings **31-38** and an uneven resistance variation of the phases are minimized.

Referring to FIGS. **1A-1D**, **2**, and **8A-8C**, during a stage **S112** of routine **110**, controller **51** determines the holding position of rotor **40** as previously described herein in connection with stage **S102** (FIG. **7A**). During a stage **S114** of routine **110**, controller **51** determines a motor torque corresponding to the holding position of rotor **40**. In one embodiment, controller **51** retrieves the motor torque from a lookup table in memory **53**. For example, as shown in FIG. **8B**, controller **51** can retrieve a motor torque level corresponding to an intersection of a holding position **A** corresponding to phase **C** aligned (FIG. **1C**) and a motor torque curve **MTC<sub>1</sub>**.

During a stage **S116** of routine **110**, controller **51** controls a reduction of an ampere level of a phase current corresponding to the holding position of rotor **40**. The reduction in ampere level is accomplished by controller **51** directing interface **54** via commutation control signal **CCs** to reduce the ampere level of the excited phase current. In one embodiment of stage **S116**, the adjustment of the ampere level maintains a motor torque level that is greater than the load torque being applied to the actuating member coupled to rotor **40**.

For example, as shown in FIG. **8C**, when phase **C** aligned corresponds to the holding position, interface **54** directs a flow of phase current **I<sub>PS3</sub>** at an ampere level **X<sub>1</sub>** through winding **33** and winding **37** for time period **t<sub>10</sub>** to maintain rotor **40** in the holding position. Thereafter, interface **54** then directs a flow of phase current **I<sub>PS3</sub>** at an ampere level **X<sub>2</sub>** through winding **37** and winding **37** for time period **t<sub>11</sub>** to thereby establish a level of motor torque corresponding to an intersection of a position **B** of rotor **40** and a motor torque curve **MTC<sub>2</sub>** as shown in FIG. **8B** while maintaining rotor **40** in the holding position.

Controller **51** returns to routine **110** upon completion of stage **S116**. Those having ordinary skill in the art will appreciate that a benefit of routine **110** is a minimization of current while maintaining rotor **40** in a holding position.

5 Referring again to FIG. 3, routine **60** as described herein is intended to be utilized in systems requiring pre-alignment stage **S62**, preliminary stage **S64** and primary stage **S66**, such as, for example, an electric caliper brake system. Nevertheless, one of the stages **S62-S66** of routine **60** can be individually implemented within a system, and two of the stages **S62-S66** of routine **60** can be 10 jointly implemented within a system. Also, any embodiments of the various embodiments of stages **S62-S66** such as routine **70** (FIG. 4A), routine **80** (FIG. 5A), routine **90** (FIG. 6A), routine **100** (FIG. 7A) and routine **110** (FIG. 8A) can be individually or jointly implemented within systems.

15 While the embodiments of the present invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the spirit and scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

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